

Research Report
KTC-99-21

EVALUATION OF ROAD WEATHER INFORMATION SYSTEM

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May 1999

1. Report No. KTC-99-21		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Evaluation of Road Weather Information System				5. Report Date May 1999	
				6. Performing Organization Code	
7. Author(s) Joel M. Weber, R. Clark Graves, and Jerry G. Pigman				8. Performing Organization Report No.6 KTC-99-21	
9. Performing Organization Name and Address Kentucky Transportation Center College of Engineering University of Kentucky Lexington, KY 40506-0281				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Kentucky Transportation Cabinet State Office Building Frankfort, KY 40622				13. Type of Report and Period Covered Final	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the Kentucky Transportation Cabinet.					
16. Abstract The objectives of this study were to monitor and evaluate the Kentucky Transportation Cabinet's Road Weather Information System (RWIS). Six systems were installed and all became operational in November 1997. Each site includes sensors which measure temperature, precipitation, relative humidity, wind speed, pavement temperature, surface condition, and chemical concentration. The data can be accessed remotely using a Windows-based software program. The data are also stored in a central database for future use. The accuracy of the system was evaluated through comparison of atmospheric data with airport data and through site observations of surface condition, pavement temperature, and air temperature. The reliability was evaluated by reviewing the history log files to locate gaps in the data. Problems with individual sensors were also documented. The accuracy of the system was found to be good for the sensors that could be directly evaluated. The reliability was satisfactory with the larger gaps in data being caused by delays in detecting minor problems. Maintenance of the system was a problem during the evaluation period. Additional installations of RWIS are not recommended until a more formalized process is developed by the Kentucky Transportation Cabinet for use of the data in management of winter weather events.					
17. Key Words Anti-icing Winter maintenance Road Weather Information System (RWIS)			18. Distribution Statement Unlimited, with approval of the Kentucky Transportation Cabinet		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 30	
				22. Price	

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EXECUTIVE SUMMARY

The objectives of this study were to monitor and evaluate the Kentucky Transportation Cabinet's Road Weather Information System (RWIS). Six systems have been installed and all were operational by November 1997. Each site includes sensors which measure temperature, precipitation, relative humidity, wind speed, pavement temperature, surface condition, and chemical concentration. The data can be accessed remotely using a Windows-based software program. The data are also stored in a central database for future use.

The accuracy of the system was evaluated through comparison of atmospheric data with airport data and through site observation of surface condition, pavement temperature and air temperature. The reliability was evaluated by reviewing the history log files to locate gaps in the data. Problems with individual sensors were also documented.

The accuracy of the system was found to be good for the sensors that could be directly evaluated. The reliability was satisfactory with the larger gaps in data being caused by delays in detecting minor problems. Maintenance of the system was a problem during the evaluation period.

Additional installations of the system in its present form are not recommended. A recommended alternative is the installation of air temperature and pavement temperature sensors at strategic locations across the state.

1.0 INTRODUCTION

Several states have been using ice detection systems and weather forecasting services since 1962. Over thirty years of development have lead to the systems in use today. A Road Weather Information System (RWIS) allows the monitoring of highway conditions at multiple sites from one central location. Meteorological conditions such as temperature, precipitation, relative humidity, and wind speed can be monitored at each location. The pavement temperature and the presence of moisture, ice, or snow are also reported.

Controlling snow and ice requires large expenditures of labor and materials. Applying pretreatment for a storm that does not materialize wastes valuable resources. Delaying to confirm a storm prevents early treatment and increases the resources necessary to clear the road. An efficient process would mobilize the appropriate resources within a proper time frame.

Treatment decisions by the Kentucky Department of Highways are made using National Weather Service forecasts, weather radar data, and field observations by someone driving the roads. Weather and roadway sensors can be used to provide operations managers with timely information about changing conditions. The pavement and meteorological sensors can be used to monitor current conditions, detect critical conditions, and help predict future conditions. The data from the weather system can be used to supplement, not replace, the current decision making process.

Most states use some type of RWIS to help control snow and ice. There are few published reports about these systems, but studies have shown that information from a weather system can reduce the equipment, material, and personnel needed to maintain roads during winter weather. A Federal Highway Administration study found that the agencies using the systems have been satisfied with their performance and made the following conclusions (1):

1. The use of ice detection and highway information systems can lower resource usage and enable more timely treatment of icing conditions.
2. A learning period is required for users to develop a feel for and trust in the information from the system.
3. Acceptance and use of the system was influenced by the reliability of the system hardware.
4. Effective system location and a process to incorporate the new information are crucial to success.
5. A regional system which allows for information sharing between jurisdictions provides additional benefits.
6. Interjurisdictional cooperation is a key to success.
7. Ice detection and highway weather information systems are considered to be proven technology.

The Kentucky Department of Highways' Division of Operations selected six locations at which a Remote Processing Unit (RPU) and the related sensors were installed. All six sites became operational as of November 17, 1997. One of the sites was installed in conjunction with an anti-icing system at the I-75 and US 25E interchange. The system was monitored to evaluate the accuracy,

reliability and potential for further use. The six locations are:

- I-75 Clays Ferry Bridge;
- I-75 & I-64 Interchange, East of Lexington;
- I-275 & KY 17 Interchange, Covington;
- I-265 & KY 1447 (Westport Rd.) Interchange, Louisville;
- I-65 Kennedy Bridge, Louisville; and
- I-75 & US 25E Interchange, Corbin.

A preliminary evaluation of Kentucky's RWIS was conducted by the University of Kentucky's Transportation Center and the results were documented in December 1997 as Report KTC-97-26, titled "Evaluation of Road Weather Information Systems: Interim Report" (2).

2.0 RWIS INSTALLATIONS

2.1 CLAYS FERRY BRIDGE

This site is located at the Clays Ferry Bridge on I-75 at milepoint 97.5 in Fayette County. The equipment includes the RPU, a visibility sensor, and various atmospheric sensors. The total cost for the system was \$176,770.

The atmospheric sensors and two temporary pavement sensors were installed in June 1996. The pavement sensors were located on the center bridge and its northbound departure. Both were in the left wheel path of the right lane. The RPU and atmospheric sensors are located near the northbound lanes north of the bridge. The visibility sensor is located northeast of the bridge below the bridge deck. The sensor locations are shown on Figure 1. The temporary pavement sensors were used until August 25, 1997. The installation of the permanent sensors was completed in November 1998. Three of the permanent pavement sensors are on the bridge, and the other is on the northbound departure. The locations of the permanent sensors are shown in Figure 2. The system began operating on January 15, 1997, and continuous data collection began on March 27, 1997.

2.2 I-75 & I-64 INTERCHANGE

This site is located on I-75 at milepoint 111.2 in Fayette County. It is at the interchange of I-75 and I-64 east of Lexington. The site includes a RPU, four pavement sensors, and various atmospheric sensors. The total cost of the system was \$99,500.

The atmospheric sensors and pavement sensors were installed in December 1996. The pavement sensors are located on the I-75 southbound bridge, the departure of the I-75 southbound bridge, the I-75 northbound bridge, and the bridge of the I-64 westbound off ramp. All pavement sensors are in the center of the right lane. The RPU and atmospheric sensors are located between the

I-75 southbound lanes and the I-64 westbound off ramp. The sensors locations are shown on Figure 3. The system at this site began operating on January 10, 1997, with continuous data collection on March 27, 1997.

2.3 I-275 & KY 17 INTERCHANGE

This site is located on I-275 at milepoint 79.8 in Kenton County. It is at the interchange of I-275 and KY 17 south of Covington. The site includes a RPU, four pavement sensors, and various atmospheric sensors.

The RPU and sensors were installed in February 1997, at a cost of \$75,991. The pavement sensors are located on the I-275 eastbound approach, the I-275 eastbound bridge, the I-275 westbound bridge, and on KY 17 northbound. The sensors in eastbound lanes are in the left wheel path of the left lane and the other sensors are in the right wheel path of the right lane. The RPU and atmospheric sensors are north of I-275 and east of KY 17. The locations of all sensors are shown in Figure 4. The system at this site became operational on May 9, 1997, and continuous collection began on May 20, 1997.

2.4 I-265 & KY 1447 INTERCHANGE

This site is located on I-265 at milepoint 32.5 in Jefferson County. It is east of Louisville at the interchange of I-265 and KY 1447 (Westport Road). The site includes a RPU, four pavement sensors, and various atmospheric sensors.

The RPU and sensors were installed in February 1997, at a cost of \$75,304. The pavement sensors are located on the I-265 northbound approach, the I-265 northbound bridge, the I-265 southbound bridge, and KY 1447 eastbound. The northbound bridge sensor is in the center of the right through lane, and the southbound bridge sensor is in the left wheel path of the left lane. The other pavement sensors are in the right wheel path of the right lane. The RPU and atmospheric sensors are located east of I-265 between the exit ramp and KY 1447. The sensor locations are shown in Figure 5. The system at this site began operating on August 20, 1997.

2.5 KENNEDY BRIDGE

This site is located at milepoint 136.7 of I-65 on the Kennedy Bridge in Louisville. The equipment includes the RPU, four pavement sensors, and various atmospheric sensors.

The RPU and sensors were installed in April 1997 at a cost of \$71,229. Two pavement sensors are located on the south end of the bridge and two others are on the ramp from I-64 westbound to I-75 northbound. The RPU and atmospheric sensors are east of the bridge between I-64 and River Road. The sensor locations are shown in Figure 6. The system at this site began

operating on November 17, 1997.

2.6 I-75 & US 25E INTERCHANGE

This site is located on I-75 at milepoint 28.9 in Laurel County. It is at the interchange of I-75 and US 25E near Corbin. A bridge anti-icing system has also be installed on the southbound bridge at this interchange. The anti-icing system is being evaluated under another research project.

The RPU and sensors were installed in September 1997 at a cost of \$68,417. The pavement sensors are on the northbound bridge, the southbound bridge, the southbound approach, and the southbound exit ramp. The ramp sensor is in the left wheel path, the northbound bridge sensor is in the left wheel path of the left lane, and the other two are in the right wheel path of the right lane. The RPU and atmospheric sensors are located between the southbound bridge and exit ramp. The sensor locations are shown in Figure 7. The system began operating on September 12, 1997.

3.0 SYSTEM CAPABILITIES

The Road Weather Information System is controlled by a Central Processing Unit (CPU) located at the Division of Operations' offices of the Kentucky Department of Highways in Frankfort. This CPU accesses and stores the atmospheric and surface data that is collected by the RPUs. Data from the CPU can be accessed remotely using a Windows based client software program developed by the manufacturer. A sample screen from the software is shown in Figure 8. All of the weather systems currently being evaluated were provided by Surface Systems Incorporated.

Each user has the option of configuring the client software to meet their needs. The user can specify English or metric units, time options, map colors, history display options, data refresh rates, and data sources. Individual configurations can be saved and protected by passwords.

The client software can display both regional maps and site maps. The regional maps show RPU locations, and site maps show the locations the RPU and all pavement sensors. Data tags can be attached to the maps to display atmospheric and pavement data. The content and position of the data tags can be specified for each sensor.

In addition to the data tags, RPU data can be displayed through data windows, RPU status windows showing all sensors attached to the RPU, and summary data windows that show summary data from all RPUs. The reports displayed in these windows can be printed if desired.

The RPUs save data approximately every ten minutes, or when a significant change in conditions occurs. A history of the saved data is sent to the CPU along with current sensor data. Historical data from desired time periods can be downloaded from the CPU. The data can then be viewed as a sensor history window (a list of all readings for sensor during specified time period), sensor history graph (a graph of all readings for the sensor during specified time period), or quick history graph (graph of sensor readings for a predefined number of hours).

The program can also display SCAN Cast weather forecast if this service is available. Forecasts of air temperature, pavement temperature, type of precipitation, and accumulation can be viewed in a graphical format. This service was evaluated in conjunction with the site at the I-75 & I-64 interchange.

4.0 FUNCTIONALITY

4.1 DESCRIPTION OF DATA

The following list describes the types of atmospheric data that are measured by sensors at each location. The user can select which units are used to display the data from the atmospheric and pavement sensors. The tower holding the atmospheric sensors is shown in Figure 9. The precipitation is only reported when there is precipitation present, and visibility data are available at the Clays Ferry location only. The visibility sensor is shown in Figure 10.

Data age:	Age of data in minutes or time of last update
Air temperature:	Local air temperature
Dew point temperature:	Temperature at which dew develops
Relative humidity:	Percent of moisture in the air
Wind speed:	Average speed of wind during a one-minute period
Wind direction:	Average wind direction for a one-minute period
Gust speed:	Maximum wind speed measured in a one-minute period
Precipitation type:	Type of precipitation detected
Precipitation rate:	Average precipitation rate
Precipitation intensity:	Intensity of the precipitation
Accumulation:	Rainfall amount from midnight to current time
Visibility:	Average distance that you can see

The following list describes the types of pavement data that are reported by the pavement sensors at each location. A pavement sensor is shown in Figure 11. Only one sensor at each location reports subsurface temperature. The data age, surface status, and surface temperature are always reported. The other information is reported only when there is moisture present on the sensor.

Data age:	Age of data in minutes or time of last update
Surface status:	Condition of surface
Surface temperature:	Temperature of pavement sensor
Subsurface temperature:	Temperature 43 cm (17 in) below top of pavement
Freeze point:	Freezing point of the moisture on the sensor
Chemical percent:	Percent of chemical saturation in moisture
Ice percentage:	Percent of ice in the moisture
Depth:	Depth of water layer on sensor
Chemical factor:	Relative indication of chemical present

The surface condition is described as one of the following:

Dry:	Absence of moisture on the sensor.
Wet:	Continuous film of moisture on sensor with surface temperature above 32°F.
Chemical Wet:	Continuous film of water and ice mixture at or below 32°F with enough chemical to keep it from freezing.
Snow/Ice Watch:	Thin or spotty film of moisture at or below 32°F.
Snow/Ice Warning:	Continuous film of ice and water mixture at or below 32°F without enough chemical to prevent freezing.
Damp:	Thin or spotty film of moisture above 32°F.
Frost:	Moisture on pavement at or below 32°F with pavement temperature at or below the dew point temperature.
Black Ice Warning:	Moisture on pavement at or below 32°F under fog or near fog conditions.

4.2 DATA RECORDING

A database of historical data from all locations is maintained by the CPU and can be accessed remotely using the client software. Data from all sensors are recorded by the RPU's in approximately ten-minute intervals, and are stored for a short amount of time. When the CPU connects with the RPU's, any saved data are transferred to the database. The amount of data in the database depends on the frequency at which the CPU collects data from the RPU's.

During summer months, the CPU was set up to access the RPU's only once a day. This means that the database contained only one hour of data per day for each location. During the winter, the data were collected hourly so that the database contained 24 hours of data each day for all locations.

5.0 SYSTEM ASSESSMENT

5.1 ACCURACY

The accuracy of the system is an important evaluation component. Weather data from the Lexington Bluegrass Airport, the Standiford/Louisville International Airport and the Cincinnati Northern Kentucky International Airport were compared with the nearest RWIS installations for a limited time period. The precipitation, air temperature, dew point temperature, relative humidity, wind direction and wind speed were available from both the airports and the RWIS locations. The precipitation and wind direction recorded by the RWIS typically matched the airport data. The wind speed measured by the RWIS was consistently lower than the airport measurements. The comparison of other atmospheric data is shown in Table 1. In most cases, the weather conditions at the airports were very similar to those recorded by the RWIS. The distances between the airports and RWIS stations limit the usefulness of this type of comparison.

Table 1: Comparison of Airport and RWIS Data

	Lexington, I-75 & I-64	Covington, I-275 & KY 17	Louisville, I-265 & KY 1447	Louisville, Kennedy Bridge
Dates of Comparison	January 2, 3, 9 March 2, 3	February 10, 18 March 3, 10, 11	February 10, 18 March 6, 20	February 10, 18 March 6, 20
Distance to Nearest Airport	9 miles	7 miles	6 miles	13 miles
Air Temperature	Typically within 1 degree of airport temperature	Typically within 3 degrees of airport with differences of up to 8 degrees	Typically within 1 degree of airport with differences of up to 7 degrees	Typically lower than airport with differences of up to 10 degrees
Dew Point Temperature	Typically lower than airport with differences of up to 5 degrees	Typically within 2 degrees of airport with differences of up to 6 degrees	Variable with differences of up to 9 degrees	Typically lower than airport with differences of up to 14 degrees
Relative Humidity	Typically lower than airport with differences of up to 15%	Variable from 10% lower to 30% higher than airport	Variable from 15% lower to 30% higher than airport	Variable from 30% lower to 20% higher than airport

The accuracy of the air temperature and pavement temperature sensors was evaluated during field visits using a digital thermometer. A mercury thermometer was also used to measure the air temperature. The field measurements were later compared with RWIS readings stored in the database. The pavement temperature could not be measured on the Clays Ferry bridge or the Kennedy bridge due to the sensor locations and traffic volumes.

The measured air temperature was generally within one degree of the RWIS readings when the effects of direct sunlight and wind could be avoided. The pavement temperature measurements also matched the RWIS readings when the surface temperature was not changing rapidly. The sensors measure pavement temperature slightly below the surface. This can delay the sensor's reaction to rapid changes in surface temperature by as much as 20 minutes.

The personnel from the Department of Highways' district offices were asked to record surface condition, surface temperature and chemical treatment using the form shown in Appendix B. The infrared surface temperature readings were not available in District 11 and no data were collected in District 7. The observed surface conditions typically matched the RWIS data with slush often being reported as "chemical wet." In some cases, the wet roads were observed when the RWIS indicated dry conditions. This could be because the sensors are located in the wheel path which is often dry when most of the surface is wet. The sensors occasionally indicate a snow and ice warning when the surrounding pavement is dry. This occurs when salt accumulates in the cup of the sensor as shown in Figure 12. The infrared surface temperature readings matched the RWIS data except in cases when the temperature was changing rapidly. The times given for chemical treatments did not coincide with

noticeable changes in chemical factor or chemical percent.

The SCAN Cast weather prediction service was available for the I-75 and I-64 interchange. The forecasts were the same as those issued by the National Weather Service and other sources, but were updated only twice each day. The 24 hour pavement temperature forecast was not available from other sources. The general trend of pavement temperatures were accurately predicted, but the exact temperatures were less accurate.

5.2 SYSTEM RELIABILITY

Reliability is also an important issue with a weather system. The historical data show periods of missing data for various RPUs. There have also been times when the data are not updated properly or when the server in Frankfort could not be accessed. The current weather data must be available when needed during weather events if the system is to be used effectively. The reliability of the system was studied for three time periods:

- September 1997 - October 1997,
- December 1997 - March 1998, and
- December 1998 - February 1999.

The evaluation of the first time period revealed the number of times that each RPU failed to update and the amount of data missed between September 9 and October 31, 1997. The data for the Corbin site began on September 12, 1997 (it's first full day of operation), and there are no data for the Kennedy bridge location. The results of that study are shown in Table 2.

Table 2: Results of First Reliability Study (September 1997 - October 1997)

	No. of Times System Failed to Update	Number of Hours Missing	Percent of Total Time
Clays Ferry Bridge	11	14	1.5
Lexington, I-75 & I-64	8	11	1.2
Covington, I-275 & KY 17	5	6	0.6
Louisville, I-265 & KY 1447	71	295	30.9
Corbin, I-75 & US 25E	4	190	21.4

Results from the second reliability evaluation indicated the amount of data missing for each RPU during a four month period. It was assumed that data missing from all RPUs for specific time intervals indicated a problem with the CPU and that data missing from specific sites indicated an error at that RPU. Table 3 shows the amount of missing data for each RPU and the percent of that time caused by problems with the CPU. The CPU was down eight times for a total of 203 hours (81.8

percent of the missing data). A cut phone line at the I-265 & KY 1447 site caused 190 hours of missing data. If those 190 hours are not considered, less than six percent of all missing data was caused by RPU problems. Those problems could be related to the computer or the local communications network.

Table 3: Results of Second Reliability Study (December 1997 - March 1998)

	Number of Hours Missing	Percent of Total Time	Percent of Missing Data Related to the CPU
Clays Ferry Bridge	216	7.5	93.1
Lexington, I-75 & I-64	232	8.1	87.5
Covington, I-275 & KY 17	204	7.1	99.5
Louisville, I-265 & KY 1447	419	14.6	48.4
Louisville, Kennedy Bridge	205	7.1	99.0
Corbin, I-75 & US 25E	209	7.3	96.2

The final evaluation period focused only on the reliability of the CPU. During the three month period, the CPU was down three times for a total of 396 hours (18.3 percent of the time). The amount of down time was due to delays in detecting the problem rather than lengthy repairs.

5.3 MAINTENANCE PROBLEMS

The performance of each sensor is important for effective use of the system. The sensors need to be able to operate with minimal maintenance. Some problems have been observed with several of the sensors:

- A problem with the subsurface temperature sensor at the I-265 and KY 1447 interchange was detected in October 1997.
- The wind sensor at the Clays Ferry Bridge did not work properly when originally installed.
- A problem with the visibility sensor at the Clays Ferry Bridge was detected in March 1997.
- The subsurface temperature sensor installed at the Clays Ferry Bridge in November 1998 has not worked properly.
- A problem with the air temperature sensor at the I-75 and I-64 interchange was detected in January 1998.
- A problem with the subsurface temperature sensor at the I-75 and I-64 interchange was detected in July 1998.

The subsurface sensor at the I-265 and KY 1447 interchange and the wind sensor at the Clays Ferry Bridge were repaired in November 1997. The air temperature sensor at the I-75 and I-64 interchange was repaired in 1998. As of April 1999, several repair efforts have failed to correct the other problems. A pavement sensor at the Kennedy Bridge was covered during a paving operation

in August 1997 and was not replaced.

Some problems with the SCAN for Windows software have also been observed. The weather data for one or more locations occasionally failed to update when refreshing data from the CPU. Repeating the refresh command was usually successful in retrieving the missing data. The local databases that store configuration information and historical data frequently became corrupted. A repair program included with software was usually able to fix the files. In some cases, the files could not be repaired and needed to be replaced from a backup copy.

6.0 ANTI-ICING PROCESS

6.1 KENTUCKY'S PROCESS

According to the Guidance Manual for the Division of Operations, the snow and ice removal program has the following goals (3):

1. Provide bare pavement or adequate traction on road surfaces.
2. Keep traffic moving as safely and uninterrupted as feasible.
3. Provide statewide uniformity of pavement conditions within each snow removal priority system.
4. Consider economic and environmental factors while achieving safe driving conditions.

Treatment decisions are based on weather forecasts, radar data, and observed road conditions. The county foreman should contact police and toll operators working at night who can give warning of developing snow and ice conditions, maintain an inventory of chemical and abrasive stockpiles, report salt delivered and salt usage to the district office, and keep a storm log for each storm (3). In a major storm, the Division of Operations may recommend specific operations including the following (4):

1. Plow, but do not salt, until the air temperature exceeds 20 degrees Fahrenheit and is rising.
2. Do not apply salt unless calcium chloride is added.
3. Plow and use abrasives only.
4. Cease all removal operations but patrol the roads to rescue stranded motorists.

6.2 RECOMMENDED NATIONAL PRACTICE

The national recommended strategy for snow and ice control described in "Manual of Practice for an Effective Anti-icing Program" involves anti-icing techniques. The goal is to prevent a bond from forming between the snow and pavement. The information gathered about winter storms should include weather forecasts, radar and satellite data, road conditions, RWIS data, and pavement temperature forecasts. Treatment decisions for anti-icing should be based on the following criteria (4):

1. When precipitation is expected to start
2. What form it will be
3. Expected air and pavement temperatures
4. Expected temperature trends
5. Sky conditions
6. Wind speed and direction

Possible treatment decisions are to plow, apply chemical, or do nothing. Appropriate treatments are recommended by the Federal Highway Administration for various pavement temperatures for the following weather events (3):

1. Light snow storm (less than ½ inch per hour)
2. Light snow storm with periods of moderate or heavy snow
3. Moderate or heavy storm (more than ½ inch per hour)
4. Frost or black ice
5. Freezing rain storm
6. Sleet storm

7.0 RWIS STATUS IN KENTUCKY

The two sites that were completed in January 1997 received very little use during the winter months. All of the sites were in use through two evaluation winters (1997-98 and 1998-99). The personnel from the Department of Highways' district offices used the RWIS as a source of weather information, but did not make any treatment decisions based on RWIS data. Samples of the storm log and records of chemical treatment were obtained from one of the districts. The data were not detailed enough to allow an accurate cost/benefit analysis of the system.

Personnel from the central office and the district offices were asked to give their opinion of the RWIS in a survey. The survey ranked the overall value of the system as average. The sensors rated most useful were surface temperature, air temperature and surface condition. The surface temperature and air temperature were also considered the most accurate, while the surface condition received one of the lowest accuracy ratings. The visibility, depth of liquid, and humidity were considered the least accurate. A copy of the survey is found in Appendix B with the results shown in bold.

8.0 CONCLUSIONS

Several sensors, such as ice percentage and depth of liquid, received low accuracy ratings in the survey. The accuracy of those sensors could not be tested by direct measurement and comparison. The accuracy of all sensors that could be evaluated through field measurement was very good. The only significant accuracy problem was the false freeze warnings from the surface condition sensor. The accuracy of the forecast service was similar to that of other weather sources.

The CPU server and computers controlling the RPU's are occasionally interrupted for unknown reasons and need to be reset manually. This problem seems to occur more often at the server. Most large gaps in the data were caused by delays in detecting this problem and resetting the computers. The smaller gaps in the data were usually associated with the CPU. These gaps could be caused by the communication network which automatically connects to the RWIS and may have been disconnected temporarily for unknown reasons.

Various sensors will occasionally need to be calibrated or repaired. The system should be monitored regularly to detect problems with RPU's and individual sensors. Some unsuccessful attempts to repair sensors during the evaluation period indicate that maintaining the system could be difficult.

9.0 RECOMMENDATIONS

When used properly, the data from RWIS installations can be very useful when making treatment decisions during winter weather events. Use of the RWIS has been limited because Kentucky does not experience a high number of snow events during a typical winter. The benefits from this limited use would not justify the cost of installing and maintaining enough installations to adequately serve the entire state.

The survey indicated that the most useful sensors are air temperature and pavement temperature. The evaluation indicated that accuracy was not a problem with those sensors. A useful alternative to the existing system would be the installation of air temperature and pavement temperature sensors with the necessary communications equipment at strategic locations across the state. This would provide the most useful components of the current system with significantly reduced cost.

10.0 REFERENCES

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4. Ketcham, Stephen A.; Minsk, L. David; Blackburn, Robert R.; and Fleege, Ed J., "Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel," Federal Highway Administration, Report No. FHWA-RD-95-202, June 1996.

APPENDIX A

FIGURES

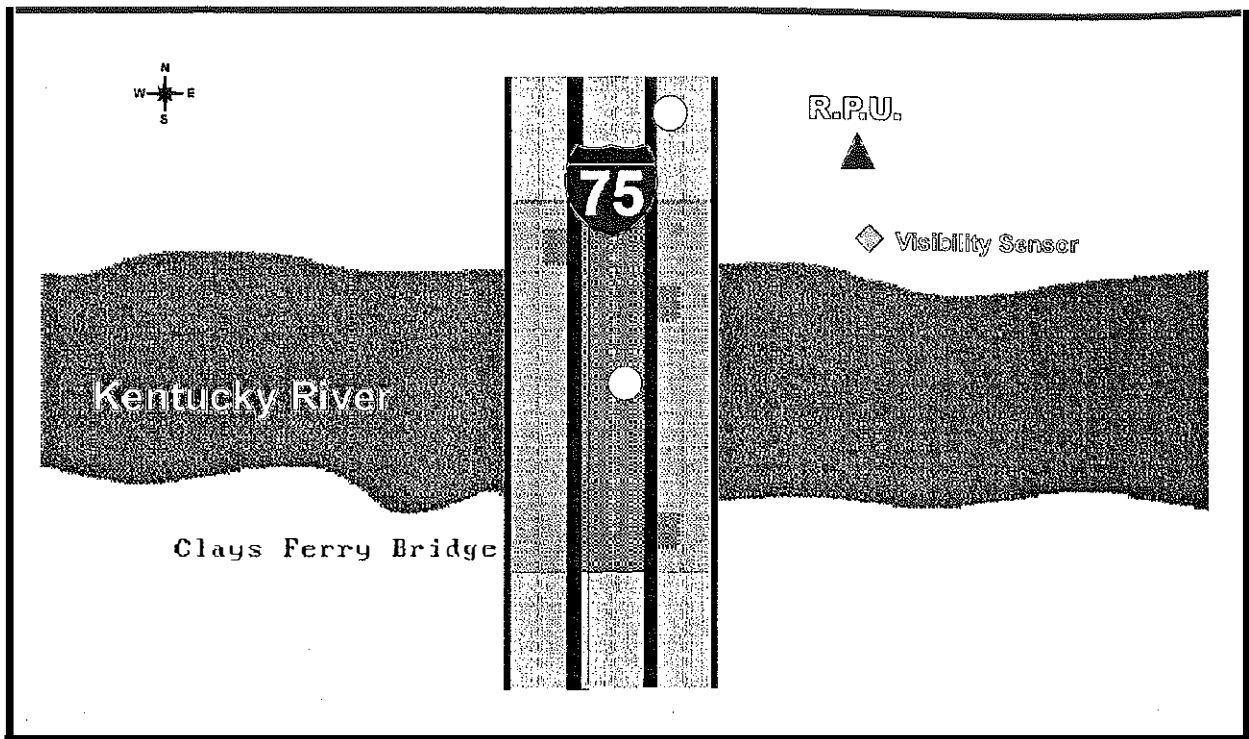


Figure 1. Temporary Sensor Locations at the Clays Ferry Bridge.

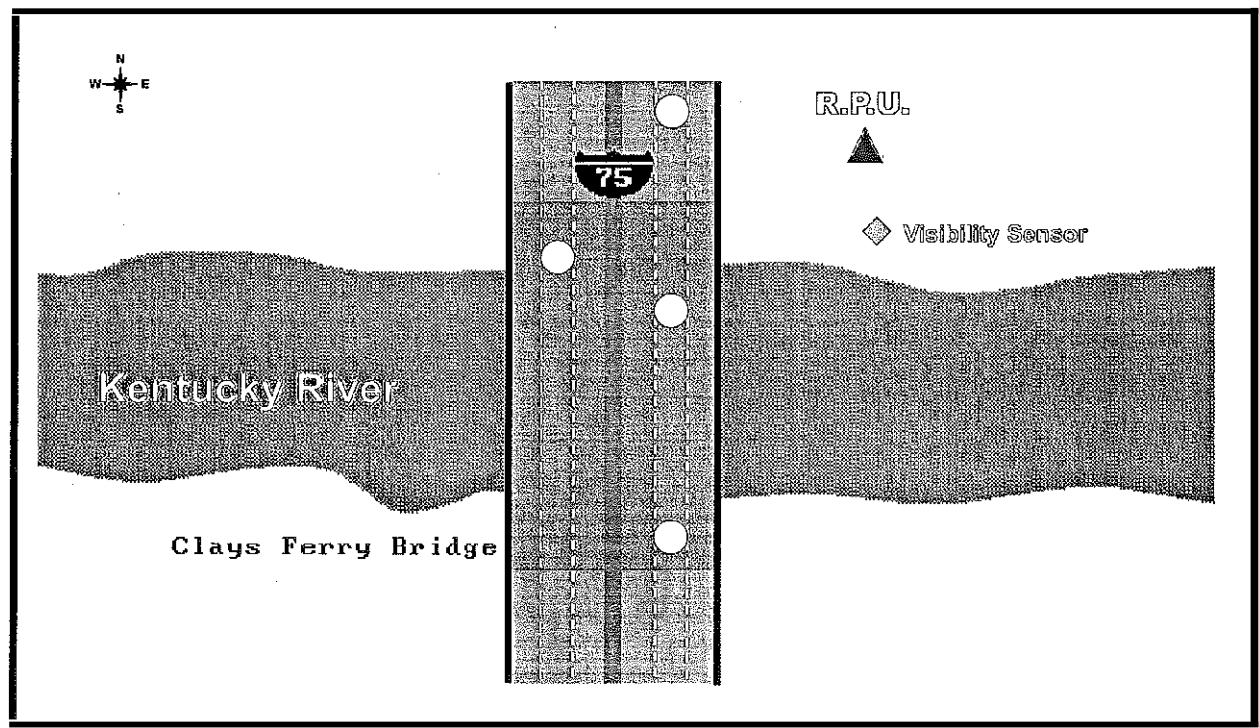


Figure 2. Permanent Sensor Locations at the Clays Ferry Bridge.

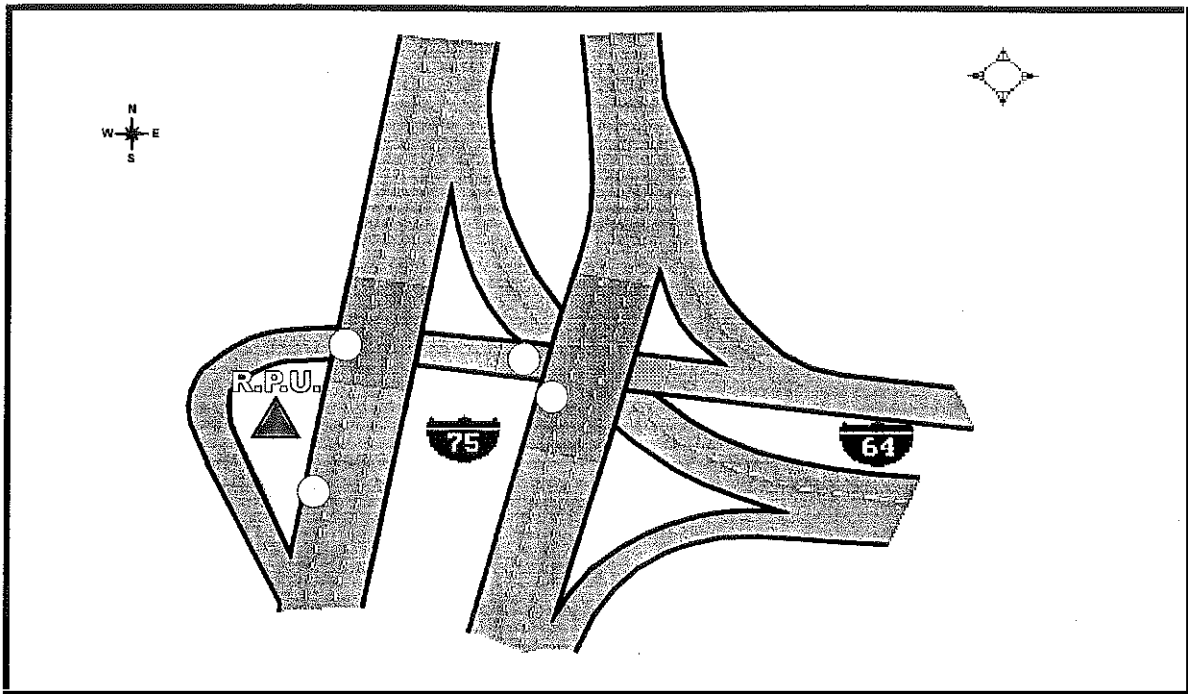


Figure 3. Sensor Locations at the I-75 & I-64 Interchange.

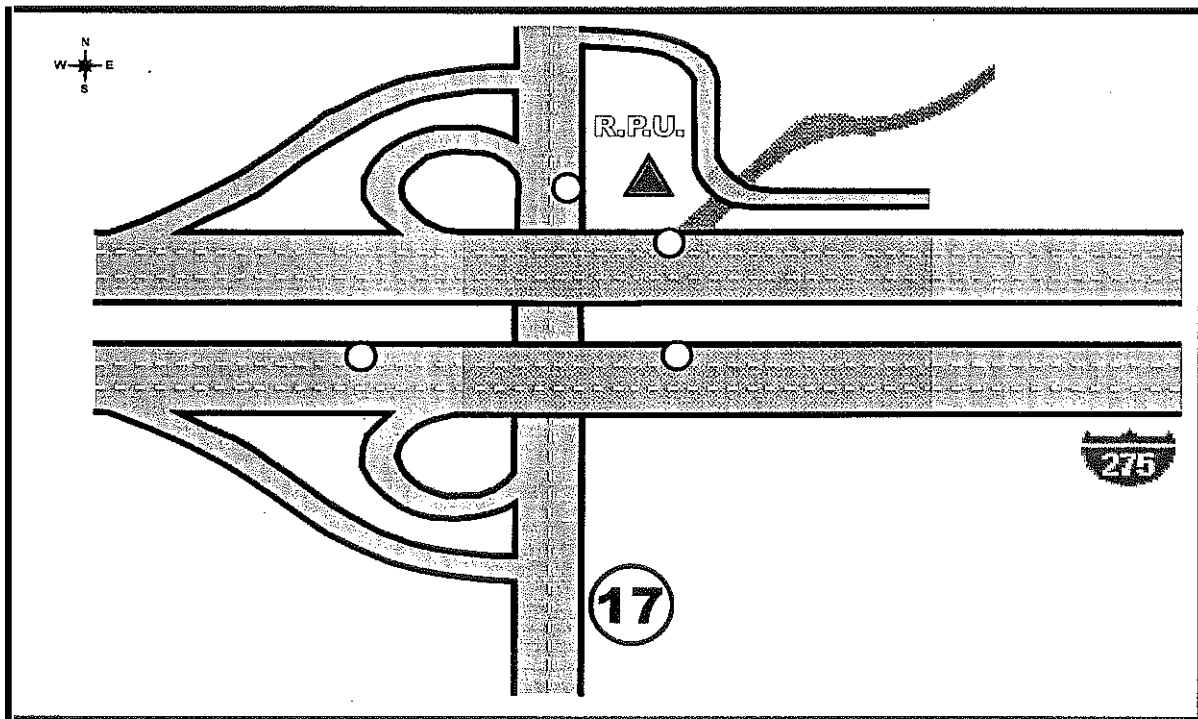


Figure 4. Sensor Locations at the I-275 & KY 17 Interchange.

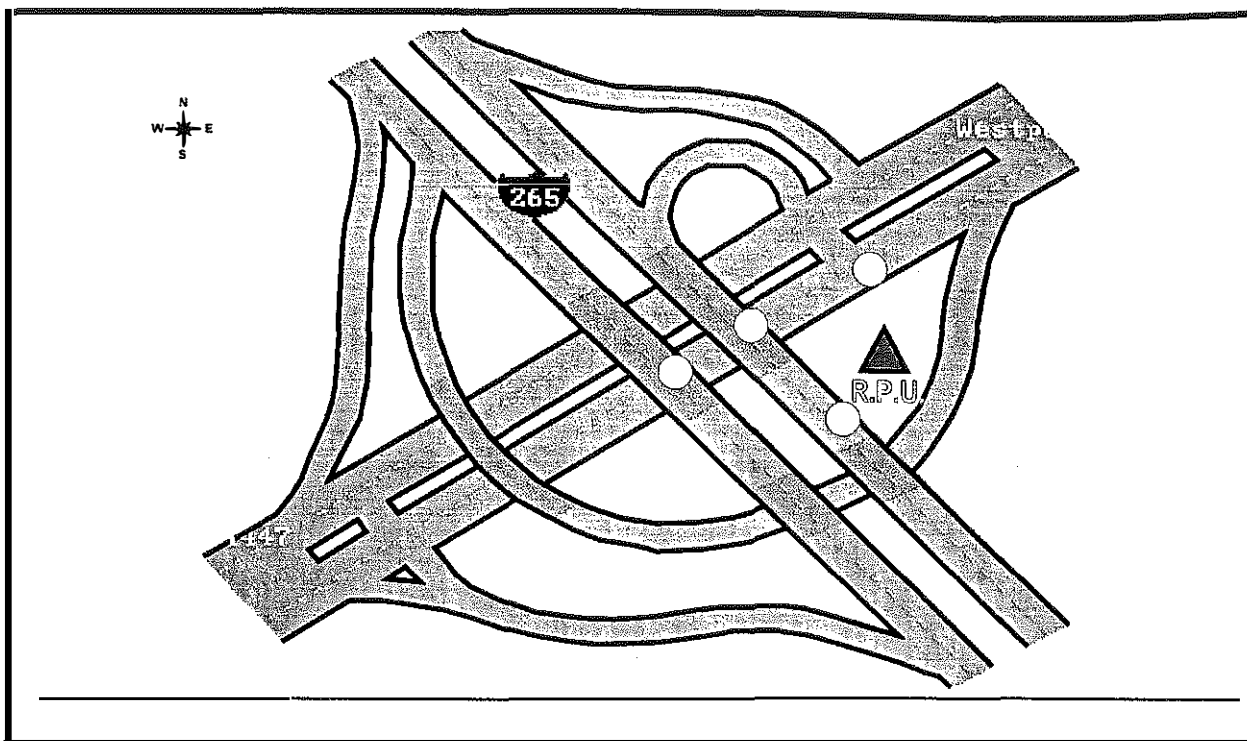


Figure 5. Sensor Locations at the I-265 & KY 1447 Interchange.

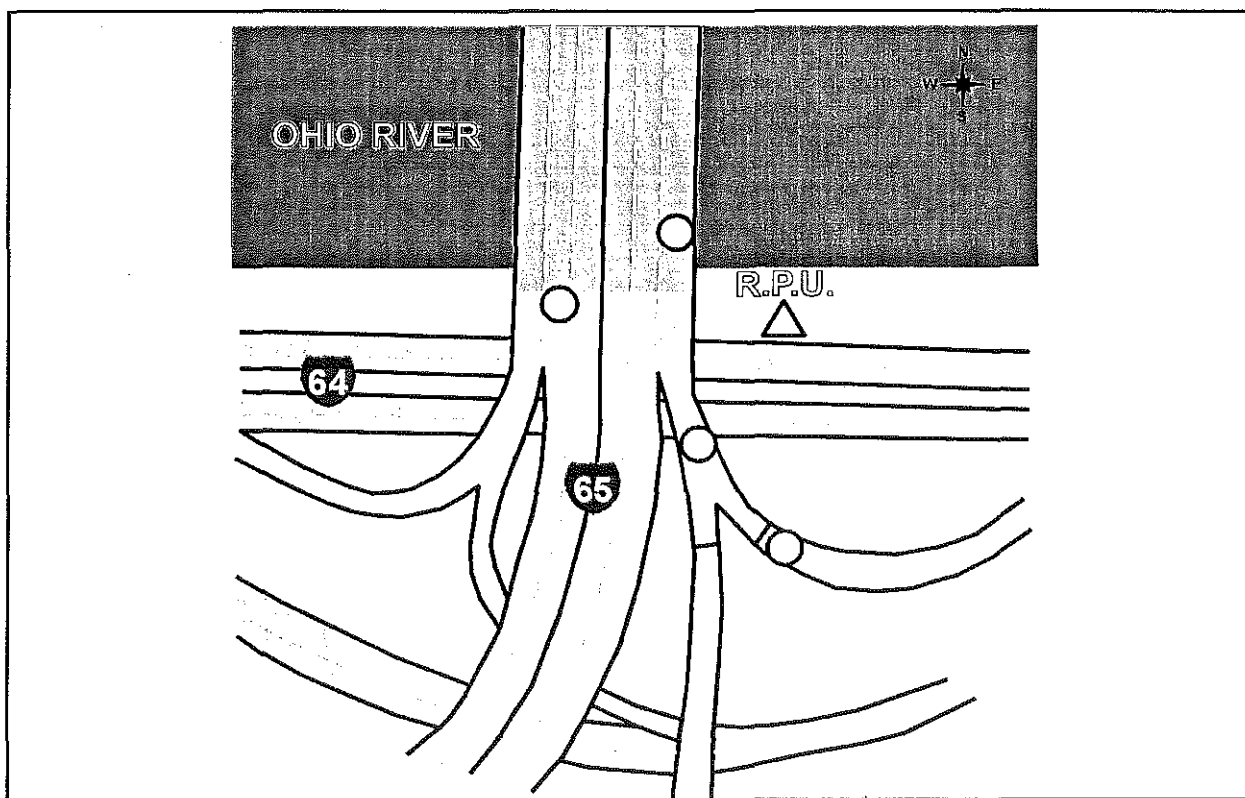


Figure 6. Sensor Locations at the Kennedy Bridge.

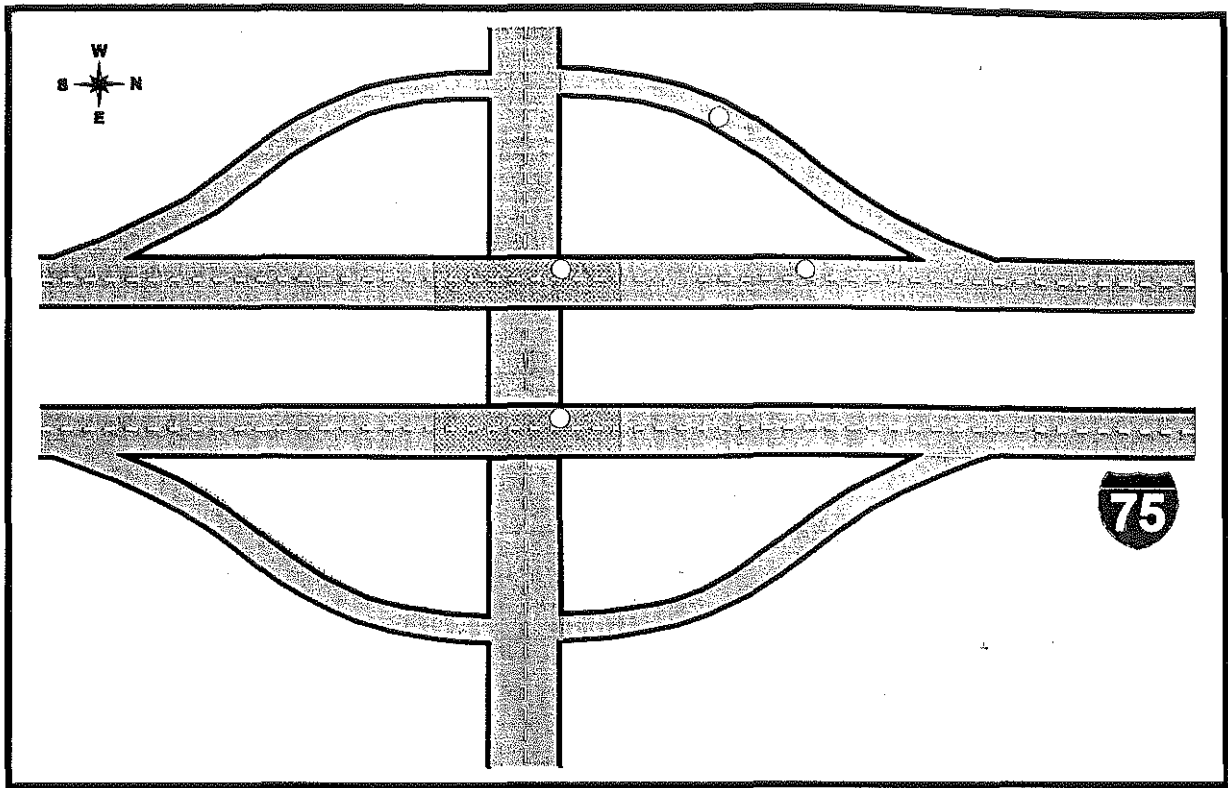


Figure 7. Sensor Locations at I-75 & US 25E Interchange.

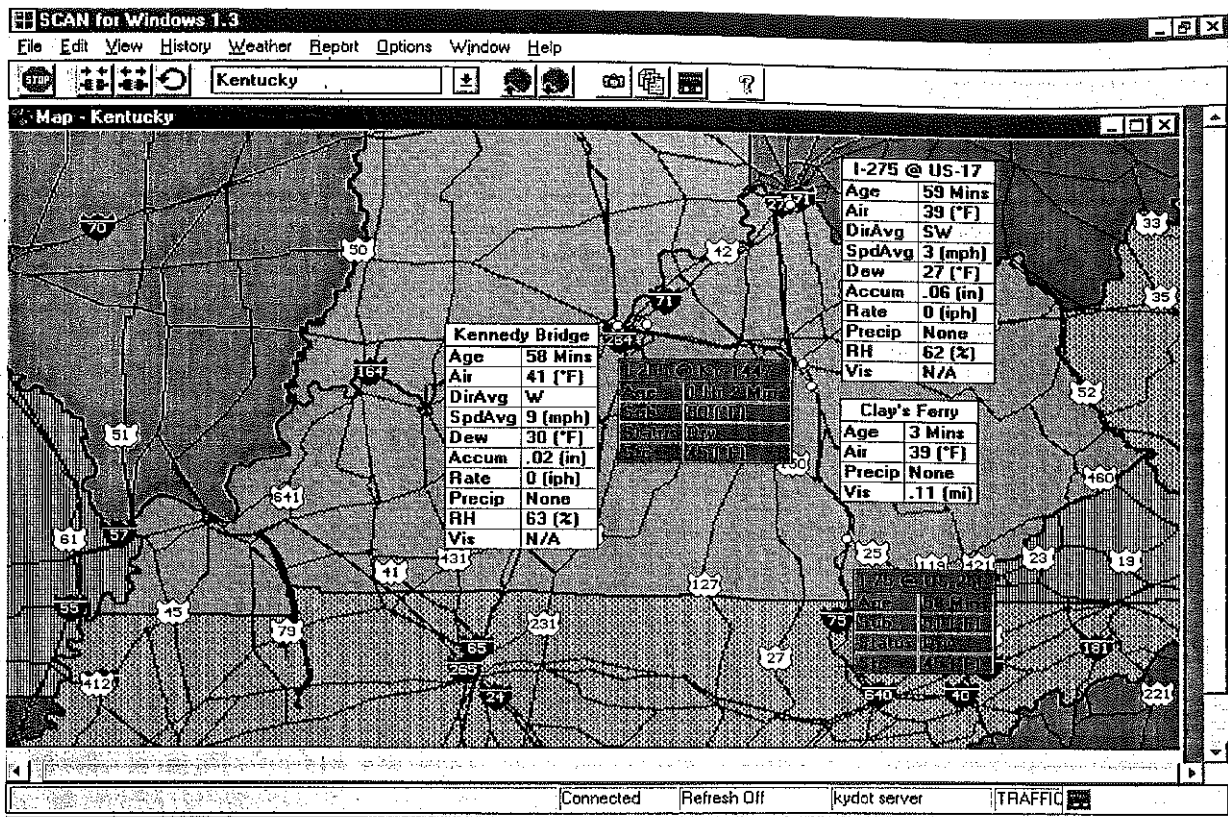


Figure 8. Sample Screen From SCAN Software.

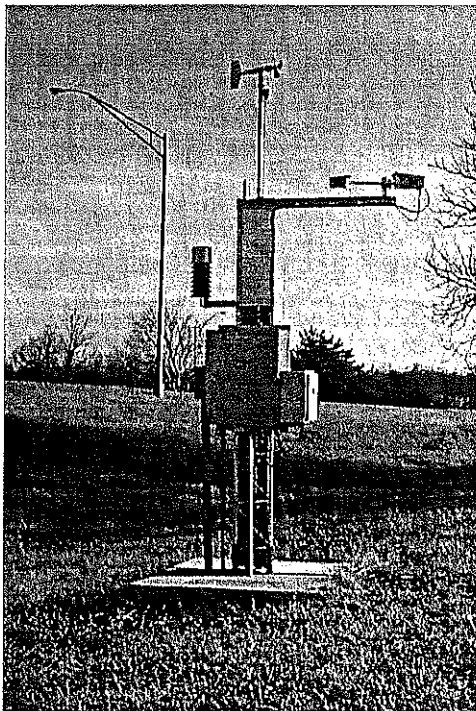


Figure 9. Atmospheric Sensors and RPU.



Figure 10. Visibility Sensor at Clays Ferry Site

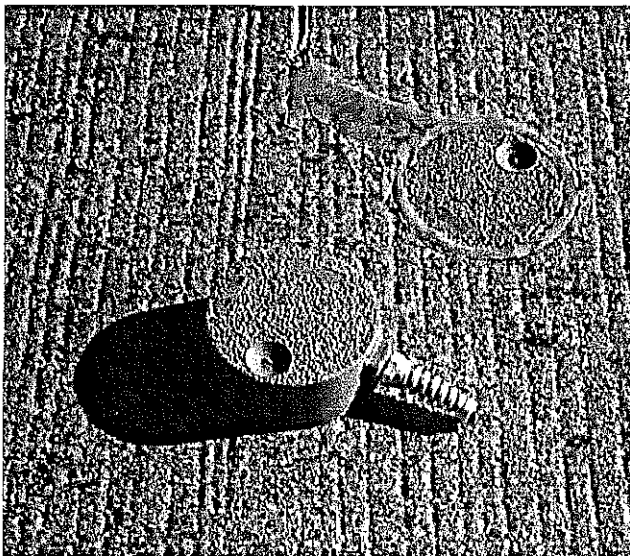


Figure 11. Pavement Sensor



Figure 12. Salt in Pavement Sensor

APPENDIX B

DATA SHEET AND SURVEY RESULTS

Field Data Collection Sheet

RWIS EVALUATION DATA
I-75 @ US 25E

Date	Time	Sensor Location	Sensor Condition	Infrared Surface Temperature		Last Known Treatment		Comments (Pavement condition, weather, etc.)	Name
				Temp.	Position and height	Time	Type		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		
		NB Deck SB Approach SB Deck SB Ramp	Dry Wet Slush Ice Snow				Liquid Cl Salt + Liquid Cl Salt Other		

RIWS SURVEY

(Results shown in bold)

1. How often has the RWIS in your district been used during snow events? (Circle one)
Regularly (**60%**) Occasionally (**40%**) Never
2. Has the RWIS data ever directly affected treatment decisions? Yes (**20%**) No (**80%**)
3. Would you recommend installing more weather stations in your district? Yes (**80%**)
No (**20%**)
4. Which sensors are the most useful? **Air Temperature, Pavement Temperature**
5. Which sensors are the least useful? **Humidity, Depth of Liquid**
6. Have you ever used the SCAN Cast weather predictions? Yes (**20%**) No (**80%**)
If yes, was it useful? **No**
7. What other sources of weather information do you use?
DTN, Weather Channel, National Weather Service, Internet, TV/Radio, Contact with other districts, Gil Gomez e-mail
8. On a scale of 1 - 5 (1 = poor, 5 = excellent), how would you rate the RWIS in the following categories?

	Poor					Excellent	Average Rating
Usefulness	1	2	3	4	5		3.4
Accuracy	1	2	3	4	5		3.2
Reliability	1	2	3	4	5		3.2
Convenience of use	1	2	3	4	5		3.8
Overall value	1	2	3	4	5		3.0

9. On a scale of 1 - 5 (1 = poor, 5 = excellent), how would you rate the usefulness of each sensor or data type?

	Poor				Excellent		Average Rating
Air temperature	1	2	3	4	5		4.0
Humidity	1	2	3	4	5		2.0
Wind speed/direction	1	2	3	4	5		2.2
Precipitation	1	2	3	4	5		3.4
Visibility	1	2	3	4	5		1.5
Surface condition	1	2	3	4	5		3.8
Surface temperature	1	2	3	4	5		4.6
Subsurface temperature	1	2	3	4	5		2.8
Chemical percent	1	2	3	4	5		2.8
Ice percentage		1	2	3	4	5	2.8
Depth of liquid	1	2	3	4	5		1.6

10. On a scale of 1 - 5 (1 = poor, 5 = excellent), how would you rate the accuracy of each sensor or data type?

	Poor				Excellent		Average Rating
Air temperature	1	2	3	4	5		4.6
Humidity	1	2	3	4	5		3.2
Wind speed/direction	1	2	3	4	5		3.4
Precipitation	1	2	3	4	5		3.4
Visibility	1	2	3	4	5		2.0
Surface condition	1	2	3	4	5		2.4
Surface temperature	1	2	3	4	5		4.2
Subsurface temperature	1	2	3	4	5		3.6
Chemical percent	1	2	3	4	5		2.8
Ice percentage		1	2	3	4	5	2.2
Depth of liquid	1	2	3	4	5		2.2

11. On a scale of 1 - 5, how would you rate the uniqueness or availability of each type of data?
(1 = easily available from other sources, 5 = only available from RWIS)

	Other Sources				RWIS Only		Average Rating
Air temperature	1	2	3	4	5		1.6
Humidity	1	2	3	4	5		1.4
Wind speed/direction	1	2	3	4	5		1.4
Precipitation	1	2	3	4	5		2.0
Visibility	1	2	3	4	5		2.0
Surface condition	1	2	3	4	5		3.8
Surface temperature	1	2	3	4	5		4.0
Subsurface temperature	1	2	3	4	5		4.6
Chemical percent	1	2	3	4	5		4.8
Ice percentage		1	2	3	4	5	4.8
Depth of liquid	1	2	3	4	5		4.0

12. What problems have you experienced with the RIWS?

Pavement sensors indicate freeze warning when pavement is dry.
Data does not always refresh every hour.
Surface condition, chemical percent, and ice percentage are unreliable.

13. Other comments?

The main use has been to monitor surface temperature.
Too spread out in the state.
Treatment policy (truck/lane/hour) is already set.
Air and surface temperature are accurate and reliable. A cheaper unit using those sensors would be good.